

PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Automatic Battery Charger

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, of 1, Tilney Street, London, W.1, a British Corporation established by Statute, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an automatic battery charging equipment, particularly for charging small secondary batteries of the kind which is suitable for supplying power to gloves knitted from insulated wire and other small heated garments.

Experience has shown that small secondary batteries of the kind referred to have an unduly short service life, mainly due to the fact that they are frequently overcharged. This is difficult to avoid unless the terminal voltage is continuously observed while the battery is on charge and the object of the invention is to provide a completely automatic charging equipment which charges the battery at a desired rate, while continuously comparing the terminal voltage with a reference potential, and automatically stops charging when the battery is fully charged. Furthermore, the battery may safely be left connected indefinitely to the charger, which will first charge it fully and then automatically recharge it at intervals, as required to maintain it in a fully charged condition. Alternatively, the charger may be arranged first to charge the battery fully and then to apply a continuous small "trickle" charge, where the battery is of a type which can accept this treatment without damage.

The invention consists of an automatic battery charging equipment comprising a pair of terminals connected to a d.c. power supply, a second pair of terminals for connection to a battery to be charged, means for establishing a reference potential, a first transistor having one electrode connected to said means

and another electrode connected to a point whose potential varies with the battery terminal voltage, the first transistor being non-conductive when the said point is positive and conductive when the said point is negative, with respect to said reference potential, a second transistor controlled by the first transistor and connected to vary said reference potential, and a third transistor also controlled by the first transistor and connected in the battery charging circuit, so arranged that in operation, when the first transistor is non-conductive the second and third transistors are conductive so that normal charging takes place and when the first transistor becomes conductive the second and third transistors become substantially non-conductive so that the charging current is substantially reduced and said reference potential is reduced.

Where a relatively heavy charging current is required a fourth transistor having a low output impedance may be connected between the second and third transistors to enable the heavy current of the third transistor to be controlled by the small current variations of the first transistor.

In a modification, for use with a d.c. supply only slightly above the battery voltage, the first, second and fourth transistors are n-p-n transistors and the third transistor is a p-n-p transistor, the collector of the fourth transistor being connected directly to the base of the third transistor, the emitter of the third transistor being connected directly to the negative supply line, whereby cutting off the fourth transistor causes collector current of the third transistor to be substantially reduced.

The circuit may either be so arranged that when the first transistor becomes conductive the charging current is reduced virtually to zero, or it may be so arranged that the charging current is reduced to a low value. Conveniently the said point is a point on a potential dividing network connected between

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the terminals of the battery. The network may comprise a potentiometer the slider of which constitutes the said point. To provide automatic compensation for temperature changes one or more portions of the network may be temperature sensitive. The portion of the network between the said point and its connection with the reference-potential establishing means may comprise a resistance having a negative temperature coefficient of resistance. The other portion of the network may comprise a resistance having a high positive temperature coefficient of resistance. Both portions of the network may have thermistors connected in parallel.

The charging current of the battery may be controlled by the contacts of a relay having its operating coil connected in the emitter circuit of the third transistor.

The reference-potential establishing-means may comprise a zener diode and a resistance in series therewith, the emitter current of the first and second transistors passing through the zener diode in the reverse direction.

Where the battery being charged is of a type which can accept a continuous trickle charge the reference-potential establishing means may comprise a battery of the same kind, whereby compensation for the variation in the battery terminal voltage with temperature changes is automatically provided. This zener diode is then unnecessary.

Preferably the power supply to the circuitry of the first and second transistors is stabilized.

In order that the invention may clearly be understood it will now be further described, having reference to the drawings accompanying the provisional specification, referred to as Figures 1 and 2, and to the drawing accompanying the complete specification, referred to as Figure 3.

In the drawings:—

Figure 1 shows a basic circuit of one embodiment of the invention;

Figure 2 shows the circuit diagram of a practical charging apparatus embodying the basic circuit of Figure 1, and

Figure 3 shows the circuit diagram of a modified charging apparatus for use with a d.c. supply only slightly above the battery voltage.

Referring to Figure 1, the equipment is provided with pair of terminals 11 and 12 for connection to a d.c. power supply having its negative pole connected to terminal 11 and its positive pole connected to terminal 12. This supplies the charging current and the power required to operate the control circuitry. The voltage of the power supply must be somewhat higher than the maximum terminal voltage of the battery to be charged and it is preferably stabilized in order to ensure precise control of the battery charging current.

A first transistor T2 functions as a trigger and has its emitter 13 connected through a reference-potential establishing-means comprising a zener diode ZD and a variable resistance R4 to the common positive line 14 which is joined to input terminal 12. The base 15 of transistor T2 is connected to the slider of a potentiometer R2 connected in series with two resistances R1 and R3 between two terminals 16 and 17 connected to the battery (18) to be charged. The collector 39 of transistor T2 is connected through a resistance R5 to the common negative line 19 joined to the input terminal 11.

A second transistor T1 has its emitter 20 connected to the point 21, which is the junction between the emitter 13 of transistor T2 and the zener diode ZD. The base 22 of the transistor T1 is connected through a resistance R6 to the junction of the collector 39 of transistor T2 and the resistance R5, while the collector 23 of transistor T1 is directly connected to the common negative line 19. The zener diode ZD is connected in the conventional manner, so that current flows through it in the reverse direction, that is to say, there is a considerable voltage drop across the zener diode ZD when current is passing to either of the emitters 13 or 20, and this voltage drop is substantially constant despite changes in current. On the other hand, the voltage drop across the resistances R4 varies directly with the current passing through it.

A third transistor T3 has its emitter 24 connected to battery charging terminal 16 and its collector 25 connected to the common negative line 19, so that the charging current of the battery passes through transistor T3. The base 26 of this transistor is connected through a resistance R7 to the junction of the collector 39 of transistor T2 and resistance R5.

Assuming that the battery is being charged at the desired rate the circuit conditions are as follows. The battery charging current passes from terminal 17 through the battery to terminal 16 and thence through transistor T3. Transistor T1 is conductive and the current to its emitter passes through resistance R4 and the zener diode ZD to the point 21 and thence to the emitter 20. The transistor T2 is non-conductive because the voltage drop across that part of the resistance network between the common positive line 14 and the slider of potentiometer R2 is less than the voltage drop across the zener diode ZD and the resistance R4. The potentiometer slider is therefore positive with respect to the point 21, that is to say, the base 15 of transistor T2 is positive with respect to the emitter 13. The base current of transistor T1 and the base current of transistor T3 both pass through resistance R5 and the potentials of the bases of these transistors are therefore

dependent upon the voltage drop across this resistance.

As charging of the battery 18 proceeds its terminal voltage rises and in consequence the voltage drop across the resistance network between the common positive line 14 and the slider of the potentiometer R2 increases. As soon as the slider becomes slightly negative with respect to the point 21 the transistor T2 begins to conduct. In consequence the voltage drop across resistance R5 is increased and the collector 39 becomes more positive. This in turn reduces the base current of transistor T1. The flow of current to the emitter 13 of transistor T2 tends to increase the total voltage drop across R4 and ZD but the reduction in the current to the emitter 20 is of greater magnitude and the net result is a reduction in the total current through R4 and ZD. In consequence the point 21 becomes more positive with respect to the slider of potentiometer R2. This has the effect of increasing the current through transistor T2, thus further reducing the current flowing to the emitter of T1. Having once been initiated, the process continues until transistor T1 is completely cut off, the current flowing to its emitter 20 being reduced substantially to zero. The increasing voltage drop across resistance R5 also reduces the base current of transistor T3 so that when a new steady condition is reached (i.e. when transistor T1 is cut off) transistor T3 is also cut off and the charging current to the battery 18 is reduced substantially to zero. If, however, the battery is of a kind which can accept a continuous small charge without damage then, by correct choice of the value of resistances R5 and R7, it may be arranged that transistor T3 is not completely cut off but the charging current to the battery is reduced to the desired low level.

The current passing through resistances R4 and zener diode ZD to the emitter of transistor T2 is smaller than the current originally passing to emitter 20 of transistor T1 so that the point 21 is now more positive than it was at the initiation of the sequence of events described above. In consequence, an appreciable fall in the terminal voltage of the battery must occur before the slider of potentiometer R2 again becomes positive with respect to point 21. When this eventually occurs, due to the battery becoming discharged, the transistor T2 is cut off, so that transistors T1 and T3 again become conductive, the charging current through the battery is restored to its initial value and the potential of the point 21 is also restored to its initial level.

It is necessary to arrange that there shall be an appreciable difference in the potential of the point 21 as between the "full charge" and "minimum charge" states of the circuit for the following reason. When fully charged,

the battery has a certain open circuit voltage but while it is being charged its terminal voltage is the charging voltage, which is equal to the true open circuit voltage of the battery plus the increment of voltage necessary to drive the charging current through the battery against its internal resistance. Consequently the cutting off of the charging current results in a drop in the battery terminal voltage from the charging voltage to the true open circuit voltage. If the potential of the point 21 were not reduced by an amount sufficient to ensure that the point 21 remains positive with respect to the potentiometer slider after the terminal voltage of the battery has fallen to the true open circuit voltage, the arrangement would be unstable and would act as a flip-flop, continually switching the charging current on and off.

The voltage of the battery varies with temperature, and falls with increasing temperature. According to another feature of the invention automatic temperature compensation may be provided to ensure that charging is commenced and terminated when the battery so requires, irrespective of variations in its voltage due to temperature. Such compensation may be provided by making the resistance R3 of a material having a high positive temperature coefficient of resistance or by making the resistance R1 of a material having a negative temperature coefficient of resistance. The temperature sensitive resistance may be incorporated in a probe at the end of a cable which may be placed near the battery or it could be incorporated in a connector which is attached to the battery. In certain cases the zener diode ZD could be replaced by a small battery of the same kind as that being charged, in which case temperature compensation would be provided by the change in voltage of the small battery which should, of course, be placed near the battery on charge. This arrangement may only be used where the batteries are of the type which will accept a continuous "trickle" charge without damage, since the emitter current of either transistor T1 or transistor T2 is always passing through the small battery as a charging current.

Figure 2 shows a complete circuit diagram of a practical charging equipment according to the invention. This incorporates the essential elements of Figure 1, which have been given like reference numerals, and it will only be necessary to describe the additional elements in full. The power supply consists of a transformer 27 having a secondary winding which is centre-tapped and also has tapings to which two rectifiers 28 and 29 may be connected in the well-known manner to provide full-wave rectification. The centre tap is connected to the common positive line 14 and the outputs of the two rectifiers are connected to the common negative line 19. A

capacitor C1 of high value functions as a reservoir and provides some degree of smoothing, and a load resistance R8 provides a permanent load to ensure that the voltage between the lines 14 and 19 does not vary to an undesirable extent when the charging current is switched on and off. A resistance R9 in the collector circuit of transistor T1 only serves to dissipate some of the power which would otherwise be dissipated in the transistor itself and resistance R10 similarly reduces the power dissipation in transistor T3. As shown, a pilot lamp 30 may conveniently be connected in parallel with this resistance to show when the battery is being charged.

The power supply to the trigger circuit consisting of transistors T1 and T2 is stabilized by means of two zener diodes ZD2 and ZD3 connected in series and a resistance R11 which conveniently may consist of a number of small lamps, the use of lamps helping to limit the current through the zener diodes. As the voltage between the lines 14 and 19 increases, the current through the zener diodes increases rapidly and this causes an increase in the temperature of the lamp filaments, which results in a substantial increase in their resistance due to their high positive temperature coefficient of resistance.

Whereas in Figure 1 the base of transistor T3 is connected through a resistance R7 to the collector of transistor T2, an additional buffer transistor T4 is introduced in Figure 2, the collector of transistor T2 being connected to the base of transistor T4 whose collector is directly connected to the negative line 19. The base resistance of transistor T3 now consists of a fixed resistance R12 in series with a variable resistance R13 by means of which the charging current through the battery may be controlled within certain limits. The transistor T4 has a low impedance output and is therefore able to deal with the relatively heavy base current of the transistor, which is capable of passing a relatively heavy battery charging current.

The base of transistor T1 is connected through resistance R6 to the junction between the emitter of transistor T4 and a resistance R14, the other end of which is connected to the common positive line 14.

As an alternative to the inclusion of the buffer transistor T4 a relay may be used, the operating coil of the relay being connected in the emitter circuit of transistor T3 in place of the battery. The charging current to the battery is then controlled by the relay contacts.

In the circuit of Figure 2 the emitter of T4 must be negative with respect to the negative terminal of the battery since it is connected through resistances R12 and R13 to the base of T3, which is in the battery charging circuit. The collector of T2 must be even more negative since it is connected to the base of T4. The negative supply line must be negative with respect to the collector of T2 by the voltage drop across resistances R5 and R11. Thus, the potential of the negative supply line 19 must be very substantially negative with respect to the negative battery terminal, that is to say, the voltage between the negative and positive supply lines 19 and 14 must be substantially greater than the battery voltage. This point is of no moment if a power supply is specially provided in accordance with Figure 2, but is very important if it is desired to use the charging arrangement according to the invention in conjunction with an existing battery charging source whose voltage is only a little above the charging voltage of the battery. This is provided for in the circuit of Figure 3, which operates in the same manner as those of Figures 1 and 2 but uses both n-p-n and p-n-p transistors. T1, T2 and T4 are p-n-p transistors, equivalent to those of like reference in Figure 2, while T3 and T5 are n-p-n transistors, but n-p-n transistors could be used in the T1, T2 and T4 positions, with p-n-p transistors in the T3 and T5 positions, the polarities of the source, the zener diodes and the battery being reversed.

Referring to Figure 3, the transistors T2 has its emitter connected to a zener diode ZD3 in series with a resistance R19 and which provide the reference potential, as in the previous circuits. The emitter of T2 is connected to a stabilized negative supply line 31 through a resistance R18. Transistor T1 has its emitter connected to the emitter of T2, as before, and has its collector connected to the negative line 31 through a resistance R16. The base of T1 is connected through a fixed resistance R15 in series with a variable resistance R17 to the emitter of transistor T4. The base of transistor T2 is connected to the slider of a potentiometer R27 which is part of a resistance network comprising R26, R28, R29 and R30, R26 and R28 being in series with R27 between the two battery terminals and R29 and R30 being thermistors respectively in parallel with R26 and R28 to provide temperature compensation. The change-over of transistor T2 from the non-conducting to the conducting state again depends upon the relative potentials of the emitter of T2 connected to the reference source ZD3 and the potential of the slider of the potentiometer R27 representing the instantaneous battery voltage.

The emitter of T4 is connected through a series resistance network constituted by a fixed resistance R23, a variable resistance R24 and a fixed resistance R25 to the positive supply line 32. The resistance of R25 is very high compared with R23 and R24. A zener diode ZD4 is connected in parallel with resistance R25. The collector of transistor T4 is connected directly to the base of a transistor T3,

an n-p-n transistor which has its emitter and collector in the battery circuit and replaces the transistor T3 of Figures 1 and 2.

A zener diode ZD1 is connected between the positive line 32 and the negative line 31 to stabilize the voltage of the line 31. The zener diodes ZD1, ZD3 and ZD4 are so chosen that the zener voltage of ZD4 is appreciably higher than that of ZD3 and less than that of ZD1.

A second n-p-n transistor T5 has its collector connected to the stabilized negative line 31 and its emitter connected to the main negative supply line 33. The base of this transistor is connected through a variable resistance R20 and a fixed resistance R21 in series to the positive end of a further zener diode ZD2 and to a resistance R22 which has its other end connected to the common positive line 32. The negative end of ZD2 is connected to the main negative supply line 33.

In operation, when the potential at the base of T2, which is a predetermined fraction of the terminal voltage of the battery on charge, becomes negative with respect to the negative end of the zener diode ZD3, T2 begins to conduct, the potential at its collector moves positively and carries the base of T4 with it to cause the emitter of T4 to become more positive, thus reducing the current in transistor T1. This initiates the cumulative action which causes the current to the battery to be virtually cut off or reduced to a predetermined low level, as described in connection with Figures 1 and 2. The resistances R15 and R17 are so chosen that for a given increase in current in T2 there is a larger decrease in current in T1 so that the voltage drop across ZD3 and R19 is decreased. When the collector potential of T2 moves positively a point is reached when it is less than the zener voltage of ZD4 so that the current through T4 is virtually cut off. The collector of T4 goes negative carrying the base of T3 with it, so that the latter is almost or completely cut off. The charging rate is varied by the setting of resistance R24.

The function of transistor T5 and zener diode ZD2 is to provide a constant current source for the zener diode ZD1 and transistors T1 and T2, even though the supply voltage is only slightly (for example a volt or two) in excess of the zener voltage of ZD1.

A capacitor C2 is connected between the base of transistor T1 and the stabilized negative line 31 in order to guard against a cessation of charging following an interruption of the supply current when the battery is partly charged. After such an interruption followed by resumption of the current supply charging might not recommence of the terminal voltage of the battery had already risen to a point between the "charge" and "stop charging" potentials, i.e. if the terminal volt-

age of the battery is already in the "backlash" region. Due to the presence of C2 re-establishment of the supply temporarily causes a large negative voltage pulse to be applied to the base of transistors T1 to ensure that the transistors T1 and T2 are in the un-triggered state.

WHAT WE CLAIM IS:—

1. An automatic battery charging equipment comprising a pair of terminals for connection to a d.c. power supply, a second pair of terminals for connection to a battery to be charged, means for establishing a reference potential, a first transistor having one electrode connected to said means and another electrode connected to a point whose potential varies with the battery terminal voltage, the first transistor being non-conductive when the said point is positive and conductive when the said point is negative, with respect to said reference potential, a second transistor controlled by the first transistor and connected to vary said reference potential, and a third transistor also controlled by the first transistor and connected in the battery charging circuit, so arranged that in operation when the first transistor is non-conductive the second and third transistors are conductive to permit normal charging to take place and when the first transistor becomes conductive due to the increase of the battery terminal voltage the second and third transistors become substantially non-conductive so that the charging current is substantially reduced and said reference potential is reduced.

2. An equipment as claimed in Claim 1, so arranged that when the potential of the said point becomes positive with respect to the reduced potential of the reference potential when reduced due to the fall in the battery terminal voltage the first transistor again becomes non-conductive, whereby the second and third transistors become conductive, and charging is resumed, and the reference potential is raised to its original level.

3. An equipment as claimed in Claim 1 or 2 comprising a fourth transistor having a low output impedance interposed between the second and third transistor, whereby the heavy current of the third transistor may be controlled by the small current variations of the first transistor.

4. An equipment as claimed in Claim 3 wherein the first, second and fourth transistors are p-n-p transistors and the third transistor is an n-p-n transistor, the collector of the fourth transistor being connected directly to the base of the third transistor, the emitter of the third transistor being connected directly to the negative supply line, whereby cutting off the fourth transistor causes the collector current of the third transistor to be substantially reduced.

5. An equipment as claimed in Claim 3 wherein the first, second and fourth tran-

- sistors are n-p-n transistors and the third transistor is a p-n-p transistor, the collector of the fourth transistor being connected directly to the base of the third transistor, the emitter of the third transistor being connected directly to the positive supply line, whereby cutting off the fourth transistor causes the collector current of the third transistor to be substantially reduced.
6. An equipment as claimed in Claim 1 or 2 so arranged that when the first transistor becomes conductive the charging current is virtually cut off.
7. An equipment as claimed in Claim 1 or 2 so arranged that when the first transistor becomes conductive the charging current is reduced to a low value whereby the battery continues to receive a trickle charge.
8. An equipment as claimed in any preceding claim wherein the said point is a point on a potential dividing network connected between the second set of terminals.
9. An equipment as claimed in Claim 8 wherein the network comprises a potentiometer the slider of which constitutes the said point, whereby the battery terminal voltage at which the main charging current is reduced or cut off may be adjusted.
10. An equipment as claimed in Claim 8 or 9 wherein a portion of the network is temperature sensitive to provide automatic compensation for temperature changes.
11. An equipment as claimed in Claim 10 comprising a resistance having a negative temperature coefficient of resistance between the said point and its connection to the said reference-potential establishing means.
12. An equipment as claimed in Claim 10 comprising a resistance having a high positive temperature coefficient of resistance between the said point and the end of the network which is not connected to the said reference-potential establishing means.
13. An equipment as claimed in Claim 10 comprising a Thermistor in parallel with at least one portion of the network.
14. An equipment as claimed in any preceding claim wherein said means comprises a zener diode and a resistance in series therewith, the emitter current of the first and second transistors passing through the zener diode in the reverse direction.
15. An equipment as claimed in any preceding claim comprising a relay to control the battery charging current, the operation of the relay being controlled by the third transistor.
16. An equipment as claimed in any of Claims 1 to 13, wherein said means comprises a battery of the same kind as that which is being charged, adapted to provide automatic compensation for the variation in the battery terminal voltage with temperature changes.
17. An equipment as claimed in any preceding claim comprising voltage stabilizing means to stabilize the voltage supply to the first and second transistors.
18. An automatic battery charging equipment constructed and arranged substantially as herein described with reference to Figure 1 or Figure 2 of the drawings accompanying the provisional specification or Figure 3 accompanying the complete specification.
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PROVISIONAL SPECIFICATION

Automatic Battery Charger

- We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, of 1, Tilney Street, London, W.1, a British Corporation established by Statute, do hereby declare this invention to be described in the following statement:—
- This invention relates to an automatic battery charging equipment, particularly for charging small secondary batteries of the kind which is suitable for supplying power to gloves knitted from insulated wire and other small heated garments.
- Experience has shown that small secondary batteries of the kind referred to have an unduly short service life, mainly due to the fact that they are frequently overcharged. This is difficult to avoid unless the terminal voltage is continuously observed while on charge and the object of the invention is to provide a completely automatic charging equipment which charges the battery at a desired rate, while continuously comparing the terminal voltage with a reference potential, and automatically stops charging when the battery is fully charged. Furthermore, the battery may safely be left connected indefinitely to the charger, which will first charge it fully and then automatically recharge it at intervals, as required to maintain it in a fully charged condition. Alternatively, the charger may be arranged first to charge the battery fully and then to apply a continuous small "trickle" charge, where the battery is of a type which can accept this treatment without damage.
- The invention consists of an automatic battery charging equipment comprising a d.c. source for charging a battery, a source of reference potential, a first transistor having one electrode connected to the source of reference potential and another electrode connected to a point whose potential varies with the battery terminal voltage, the first transistor being non-conductive when the said point is positive and conductive when the said point is negative with respect to the reference source, a second transistor controlled

by the first transistor and connected to vary the potential of the reference source, and a third transistor also controlled by the first transistor and connected in the battery charging circuit, so arranged that when the first transistor is non-conductive the second and third transistors are conductive so that normal charging takes place and when the first transistor becomes conductive the second and third transistors become substantially non-conductive so that the charging current is substantially reduced and the potential of the reference source is reduced.

The circuit may either be so arranged that when the first transistor becomes conductive the charging current is virtually cut off, or it may be so arranged that the charging current is reduced to a low value. Conveniently the said point is a point on a potential dividing network connected between the terminals of the battery. The network may comprise a potentiometer the slider of which constitutes the said point. To provide automatic compensation for temperature changes the portion of the network between the said point and its connection with the reference source may comprise a resistance having a negative temperature coefficient of resistance. Alternatively, the other part of the network may comprise a resistance having a high positive temperature coefficient of resistance.

The source of reference potential may comprise a zener diode and a resistance in series therewith, the emitter current of the first and second transistors passing through the zener diode in the reverse direction.

Where a relatively heavy charging current is required a fourth transistor having a low output impedance may be connected between the second and third transistors to enable the heavy current of the third transistor to be controlled by the small current variations of the first transistor. Alternatively, the charging current of the battery may be controlled by the contacts of a relay having its operating coil connected in the emitter circuit of the third transistor.

Where the battery being charged is of a type which can accept a continuous trickle charge the reference source may comprise a battery of the same kind, whereby compensation for the variation in the battery terminal voltage with temperature changes is automatically provided. The zener diode is then unnecessary.

Preferably the power supply to the circuitry of the first and second transistors is stabilized.

In order that the invention may clearly be understood it will now be further described having reference to the accompanying drawings of which:—

Figure 1 shows a basic circuit of one embodiment of the invention, and

Figure 2 shows the circuit diagram of a

practical charging apparatus embodying the basic circuit of Figure 1.

Referring to Figure 1, the equipment is provided with a d.c. power supply having its negative pole connected to terminal 11 and its positive pole connected to terminal 12. This supplies the charging current and the power required to operate the control circuitry. The voltage of the power supply is somewhat higher than the maximum terminal voltage of the battery to be charged and it is preferably stabilized in order to ensure precise control of the battery charging current.

A first transistor T2 functions as a trigger and has its emitter 13 connected through a zener diode ZD and a variable resistance R4 to the common positive line 14 which is joined to input terminal 12. The base 15 of transistor T2 is connected to the slider of a potentiometer R2 connected in series with two resistances R1 and R3 between two terminals 16 and 17 connected to the battery 18 which is being charged. The collector 19 of transistor T2 is connected through a resistance R5 to the common negative line 19 joined to the input terminal 11.

A second transistor T1 has its emitter 20 connected to the point 21, which is the junction between the emitter 13 of transistor T2 and the zener diode ZD. The base 22 of the transistor T1 is connected through a resistance R6 to the junction of the collector 19 of transistor T2 and the resistance R5, while the collector 23 of transistor T1 is directly connected to the common negative line 19. It will be observed that the zener diode ZD is so connected that current flows through it in the reverse direction, that is to say, there is a considerable voltage drop through the zener diode ZD when current is passing to either of the emitters 13 or 20, and this voltage drop is substantially constant despite changes in current. On the other hand, the voltage drop through the resistance R4 varies directly with the current passing through it.

A third transistor T3 has its emitter 24 connected to battery charging terminal 16 and its collector 25 connected to the common negative line 19, so that the charging current of the battery passes through transistor T3. The base 26 of this transistor is connected through a resistance R7 to the junction of the collector 19 of transistor T2 and resistance R5.

Assuming that the battery is being charged at the desired rate the circuit conditions are as follows. The battery charging current passes from terminal 17 through the battery to terminal 16 and thence through transistor T3. Transistor T1 is conductive and the current to its emitter passes through resistor R4 and the zener diode ZD to the point 21 and thence to the emitter 20. The transistor T2 is non-conductive because the voltage drop

between that part of the resistance network between the common positive line 14 and the slider of potentiometer R2 is less than the voltage drop through the zener diode ZD and the resistance R4. The potentiometer slider is therefore positive with respect to the point 21, that is to say, the base 15 of transistor T2 is positive with respect to the emitter 13. The base current of transistor T1 and the base current of transistor T3 both pass through resistance R5 and the potentials of the bases of these transistors are therefore dependent upon the voltage drop through this resistance.

As charging of the battery 18 proceeds its terminal voltage rises and in consequence the voltage drop in the resistance network between the common positive line 14 and the slider of the potentiometer R2 increases. As soon as the slider becomes slightly negative with respect to the point 21 the transistor T2 begins to conduct. In consequence the voltage drop through resistor R5 is increased and the collector 19 becomes more positive. This in turn reduces the base current of transistor T1. The flow of current to the emitter 13 of transistor T2 tends to increase the total voltage drop through R4 and ZD but the reduction in the current to the emitter 20 is of greater magnitude and the net result is a reduction in the total current through R4 and ZD. In consequence the point 21 becomes more positive with respect to the slider of potentiometer R2. This has the effect of increasing the current through transistor T2, thus further reducing the current flowing to the emitter of T1. Having once been initiated, the process continues until transistor T1 is completely cut off, the current flowing to its emitter 20 being reduced substantially to zero. The increasing voltage drop through resistor R5 also reduces the base current of transistor T2 so that when a new steady condition is reached (i.e. when transistor T1 is cut off) transistor T2 is also cut off and the charging current to the battery 18 is also reduced substantially to zero. If, however, the battery is of a kind which can accept a continuous small charge without damage then, by correct choice of the value of resistors R5 and R7, it may be arranged that transistor T3 is not completely cut off but the charging current to the battery is reduced to the desired low level.

The current passing through resistance R4 and zener diode ZD to the emitter of transistor T2 is smaller than the current originally passing to emitter 20 of transistor T1 so that the point 21 is now more positive than it was at the initiation of the sequence of events described above. In consequence, an appreciable fall in the terminal voltage of the battery must occur before the slider of potentiometer R2 again becomes positive with respect to point 21. When this eventually

occurs, due to the battery becoming discharged, the transistor T2 is cut off, so that transistors T1 and T3 again become conductive, the charging current through the battery is restored to its initial value and the potential of the point 21 is also restored to its initial level.

It is necessary to arrange that there shall be an appreciable difference in the potential of the point 21 as between the "full charge" and "minimum charge" states of the circuit for the following reason. When fully charged, the battery has a certain open circuit voltage but while it is being charged its terminal voltage is the charging voltage, which is equal to the true open circuit voltage of the battery plus the increment of voltage necessary to drive the charging current through the battery against its internal resistance. Consequently the cutting off of the charging current results in a drop in the battery terminal voltage from the charging voltage to the true open circuit voltage. If the potential of the point 21 were not reduced by an amount sufficient to ensure that the point 21 remains positive with respect to the potentiometer slider after the terminal voltage of the battery has fallen to the true open circuit voltage, the arrangement would be unstable and would act as a flip-flop, continually switching the charging current on and off.

The voltage of the battery varies with temperature, and falls with increasing temperature. According to another feature of the invention automatic temperature compensation may be provided to ensure that charging is commenced and terminated when the battery so requires, irrespective of variations in its voltage due to temperature. Such compensation may be provided by making the resistor R3 of a material having a high positive temperature coefficient of resistance or by making the resistor R1 of a material having a negative temperature coefficient of resistance. The temperature sensitive resistance may be incorporated in a probe at the end of a cable which may be placed near the battery or it could be incorporated in a connector which is attached to the battery. In certain cases the potential reference source consisting of the zener diode ZD could be replaced by a small battery of the same kind as that being charged, in which case temperature compensation would be provided by the change in voltage of the small battery which should, of course, be placed near the battery on charge. This arrangement may only be used where the batteries are of the type which will accept a continuous "trickle" charge without damage, since the emitter current of either transistor T1 or transistor T2 is always passing through the small battery as a charging current.

Figure 2 shows a complete circuit diagram of a practical charging equipment according

to the invention. This incorporates the essential elements of Figure 1, which have been given like reference numerals, and it will only be necessary to describe the additional elements in full. The power supply consists of a transformer 27 having a secondary winding which is centre-tapped and also has tappings to which two rectifiers 28 and 29 may be connected in the well-known manner to provide full-wave rectification. The centre tap is connected to the common positive line 14 and the outputs of the two rectifiers are connected to the common negative line 19. A capacitor C1 of high value functions as a reservoir and provides some degree of smoothing, and a load resistance R8 provides a permanent load to ensure that the voltage between the lines 14 and 19 does not vary to an undesirable extent when the charging current is switched on and off. Resistor R9 in the collector circuit of transistor T1 only serves to dissipate some of the power which would otherwise be dissipated on the transistor itself and resistance R10 similarly reduces the power dissipation in transistor T3. As shown, a pilot lamp 30 may conveniently be connected in parallel with this resistance to show when the battery is being charged.

The power supply to the trigger circuit consisting of transistors T1 and T2 is stabilized by means of two zener diodes ZD2 and ZD3 connected in series and a resistor R11 which conveniently may consist of a number of small lamps, the use of lamps helping to limit the current through the zener diodes. As the voltage between the lines 14 and 19 increases, the current through the zener

diodes increases rapidly and this causes an increase in the temperature of the lamp filaments, which results in a substantial increase in their resistance due to their high positive temperature coefficient of resistance.

Whereas in Figure 1 the base of transistor T3 is connected through a resistance to the collector of transistor T2, an additional buffer transistor T4 is introduced in Figure 2, the collector of transistor T2 being connected to the base of transistor T4 whose collector is directly connected to the negative line 19. The base resistance of transistor T3 now consists of a fixed resistance R12 in series with a variable resistance R13 by means of which the charging current through the battery may be controlled within certain limits. The transistor T4 has a low impedance output and is therefore able to deal with the relatively heavy base current of the transistor in the T3 position, which is capable of passing a relatively heavy battery charging current.

The base of transistor T1 is connected through resistance R6 to the junction between the emitter of transistor T4 and a resistance R12, the other end of which is connected to the common positive line 14.

As an alternative to the inclusion of the buffer transistor T4 a relay may be used, the operating coil of the relay being connected in the emitter circuit of transistor T3 in place of the battery. The charging current to the battery is then controlled by the relay contacts.

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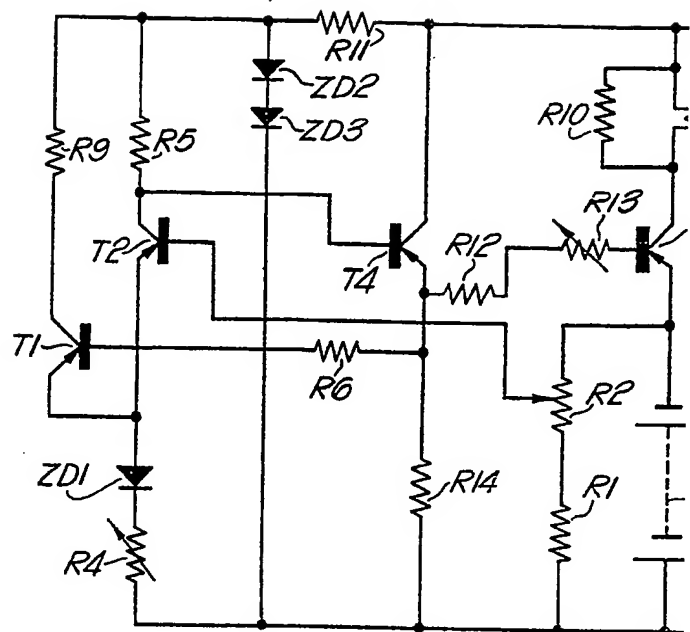
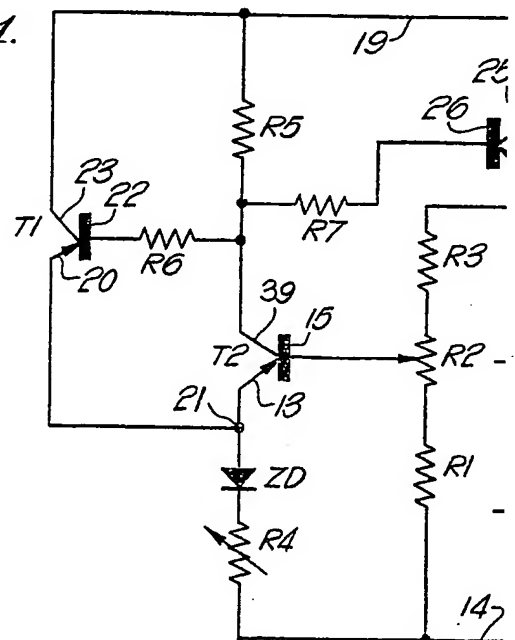


Fig. 1.



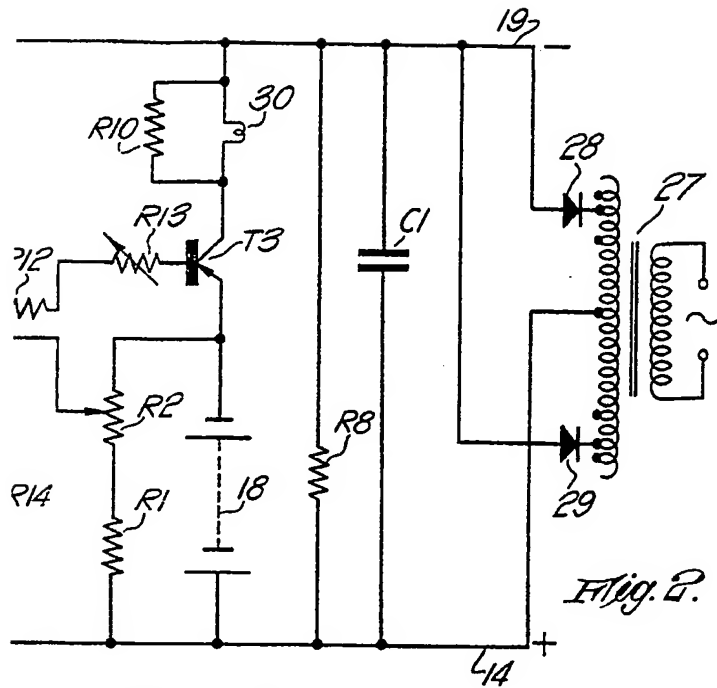
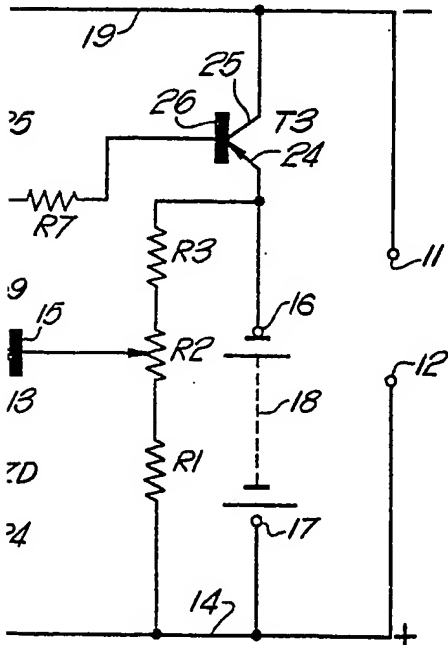


Fig. 2.



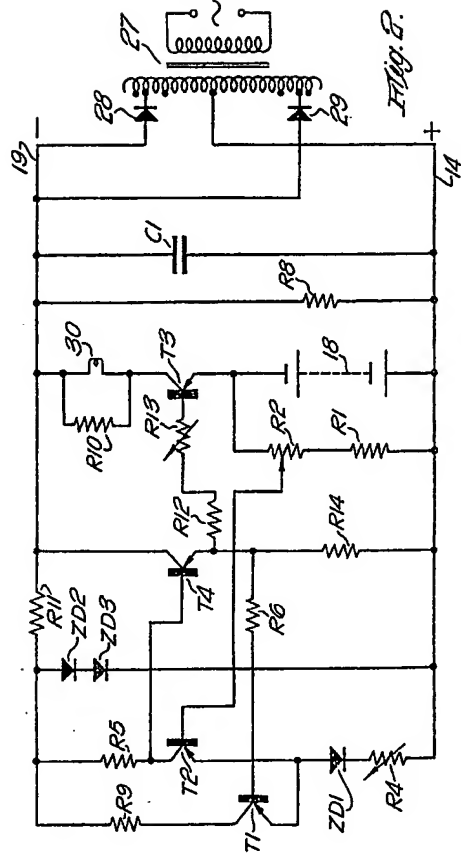


Fig. 1.

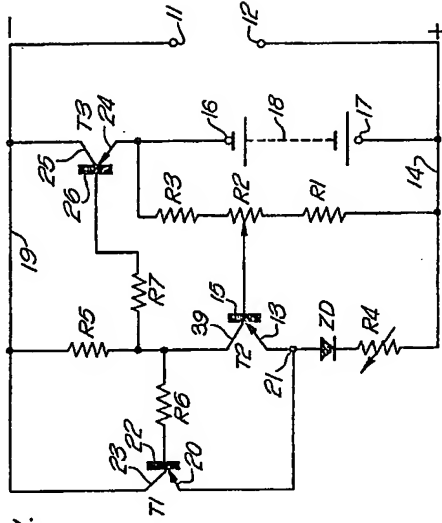


Fig. 2.

Fig. 3.

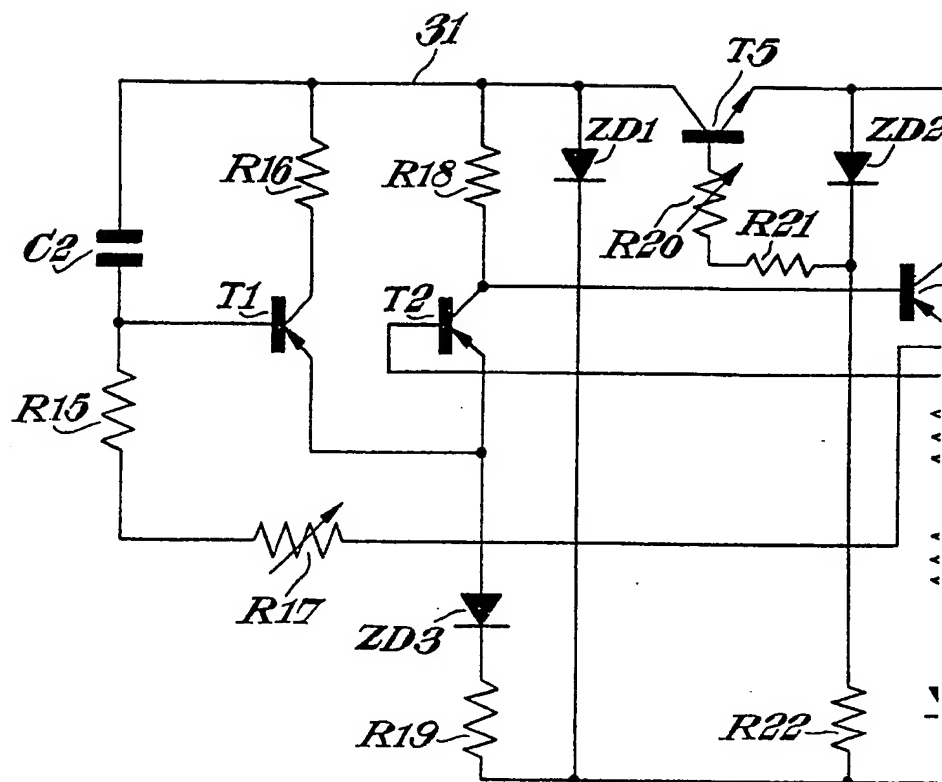


Fig. 3.

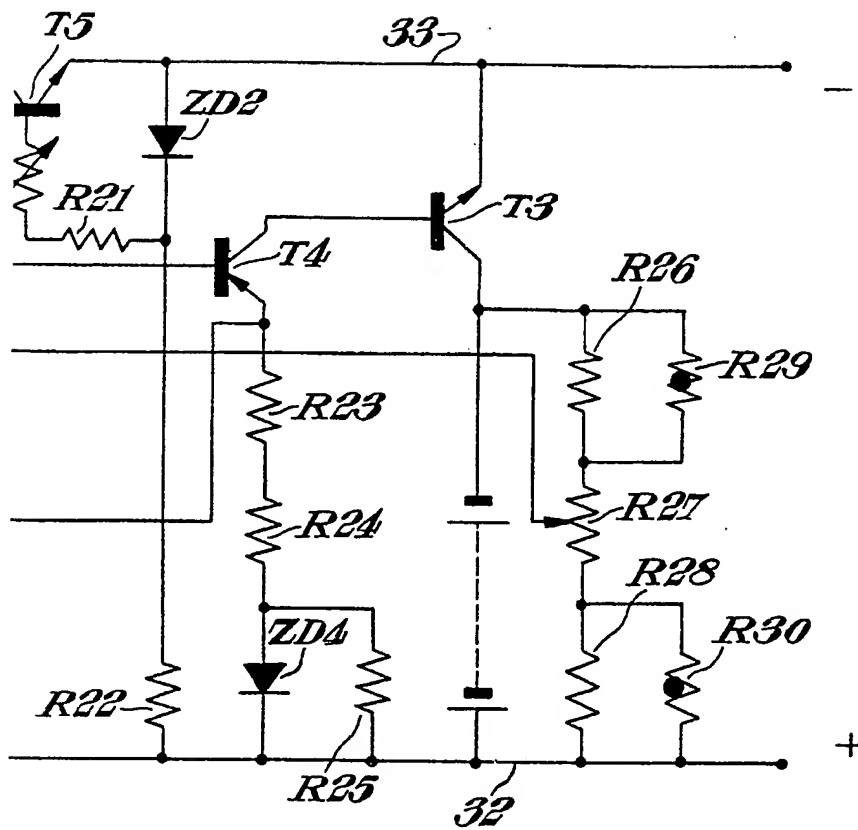


Fig. 3.

